



# Wave activity in the tropical tropopause layer and lower stratosphere as viewed by Aura MLS and compared to reanalysis data sets

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# Wave activity in the tropical tropopause layer and lower stratosphere as viewed by Aura MLS and compared to reanalysis data sets

- ▶ What are the major differences between the wave activities resolved by the RAs and the observations from Aura MLS?
- ▶ What are the effects of the QBO phase on equatorial wave activity?
  - ▶ QBO : Quasi-Biennial Oscillation : quasi-periodic oscillation of the equatorial zonal wind ( $u$ ) between easterlies and westerlies in the tropical stratosphere with a mean period of 26 to 29 months
- ▶ How do equatorial waves propagate into the stratosphere and what are their effects on the water vapor distribution in the stratosphere?

- ▶ Theory of trapped waves (Matsuno, 1966; Lindzen, 1967)
- ▶ “Vertical structure equation” and “shallow-water” equations
- ▶ Solutions to the shallow-water equations are either symmetric or anti-symmetric about the equator
- ▶ Trapped waves and dispersion relations
  - ▶ Characterized by four parameters, meridional mode number,  $n$ , frequency,  $\omega$ , planetary zonal wave number,  $k$ , and equivalent depth,  $h_e$ , of the shallow layer of fluid
- ▶ Waves propagate vertically into middle atmosphere
- ▶ Propagating systems of organized tropical convection (CCEW)
- ▶ Spectral analysis of outgoing longwave radiation (OLR), Wheeler and Kiladis (1999), *Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber-frequency domain*, JAS

# Synoptic (Reanalysis) vs Asynoptic (e.g. MLS and COSMIC GPS)

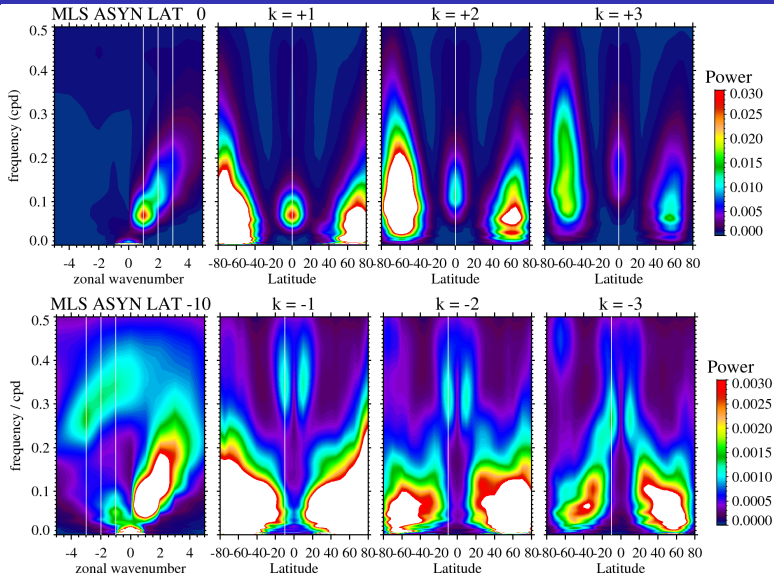
## Reanalyses, Observations and Data Gridding

- ▶ MLS and COSMIC satellite data (asynoptic) gridded using simple gaussian distance weighting, each 24h day combining ascending and descending orbits
- ▶ Synoptic reanalysis data interpolated to standard 12-levels/decade pressure surfaces and horizontally regridded to 36 by 36 by simple averaging, retaining intrinsic (3 or 6-hour) time resolution
- ▶ Asynoptic gridding of reanalyses can be performed in identical manner to the MLS data for fair comparison
- ▶ For the asynoptic gridding the regions for zonal wavenumbers  $|k|$  beyond 5-6 suffer from lack of adequate longitude resolution and frequencies above 0.25 cycles per day are increasingly suspect because of frequency aliasing

# Equatorial Trapped Waves : Variance(Lat,Freq)

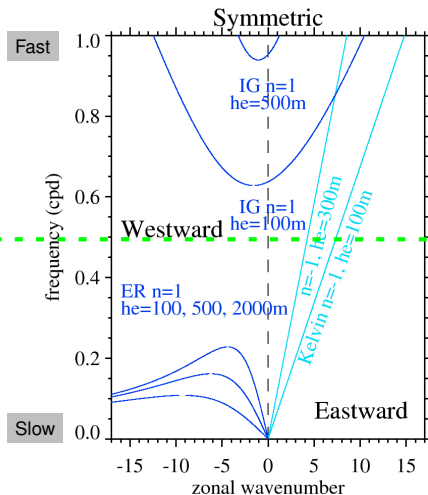
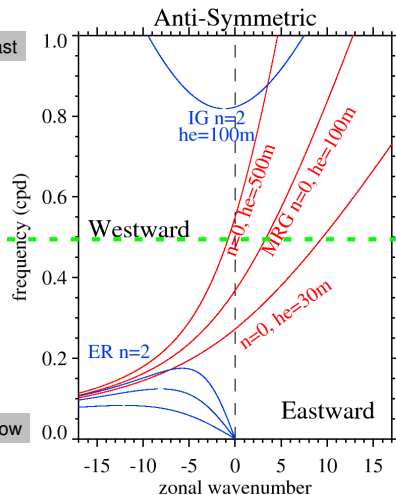
$$power = amplitude^2$$

MLS Temperature : Kelvin and Westward MRG waves : 0° and 10°S: 46 hPa : LS



# Equatorial Wave Dispersion Diagram

The dispersion relation for equatorial waves : IG – inertia-gravity  
ER – equatorial Rossby, MRG – mixed Rossby-gravity



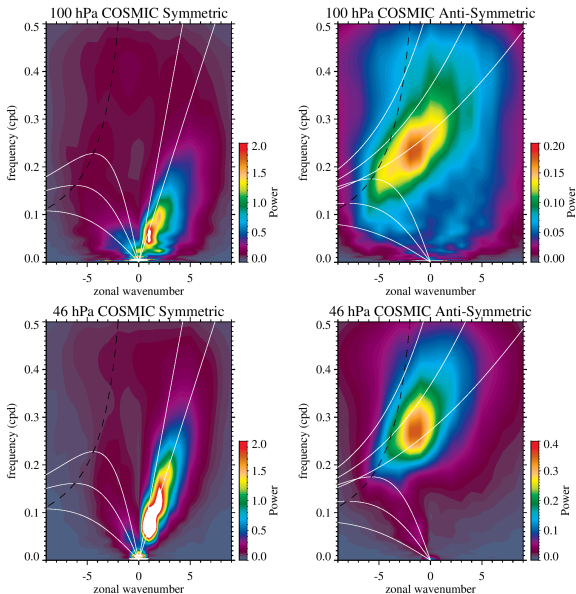
# Equatorial Wave Dispersion Relations

- ▶ Kelvin waves are a special case when the meridional velocity vanishes everywhere identically ( $v = 0$ )
- ▶ Kelvin waves are eastward propagating ( $\omega/k > 0$ ) and nondispersive
- ▶ Rossby phase velocity, is always westward,  $\omega/k < 0$ , but the group velocity,  $\partial\omega/\partial k$ , can become eastward for high wave numbers.
- ▶ When MRG phase velocity is eastward they behave like inertia-gravity waves
- ▶ When MRG phase velocity is westward they behave like Rossby waves

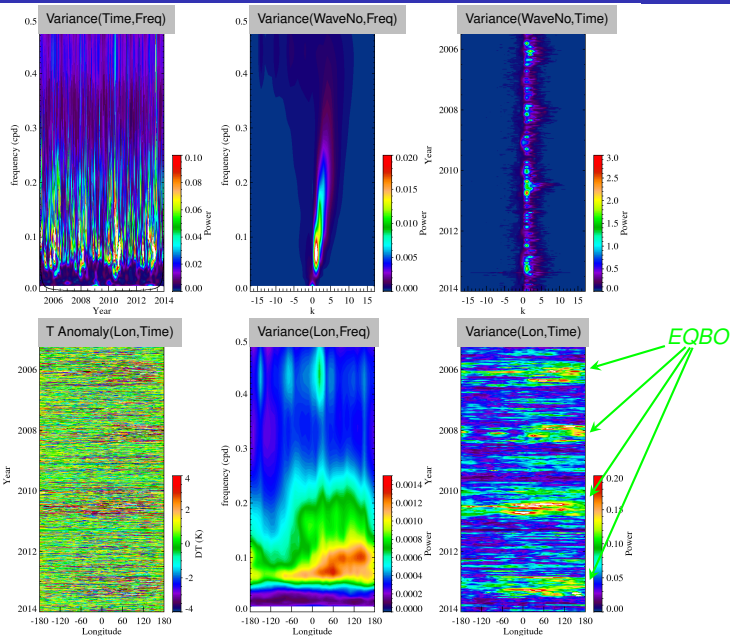
- ▶ Spectral analysis using wavelets to decompose a 1D time series into a 2D time-frequency space
- ▶ Torrence and Compo (1998), (TC98), *"A Practical Guide to Wavelet Analysis"*, *BAMS*
- ▶ Wavelet power spectrum (variance)
- ▶ Reconstruction of filtered waveforms
- ▶ Power averaging in time (e.g. monthly, seasonal, QBO phases)
- ▶ Power averaging in frequency (scale) (e.g. band-pass)
- ▶ Separation of traveling waves, Eastward and Westward

# COSMIC GPS Temperatures : 100 hPa (TTL) and 46 hPa (LS)

symmetric and anti-symmetric waves about the equator  $\pm 15^\circ$

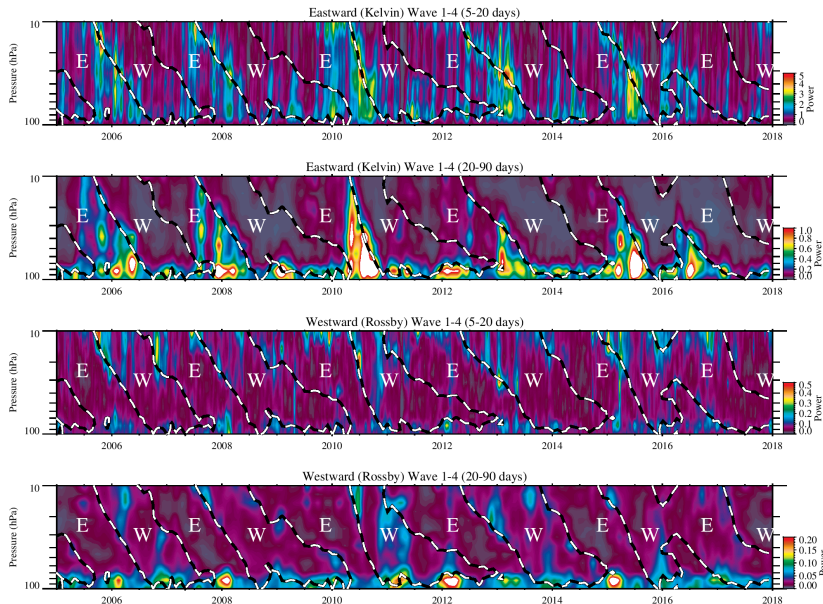


# MLS : Equator : 46 hPa : 2005-2014 : LS : $p \geq 90 d$



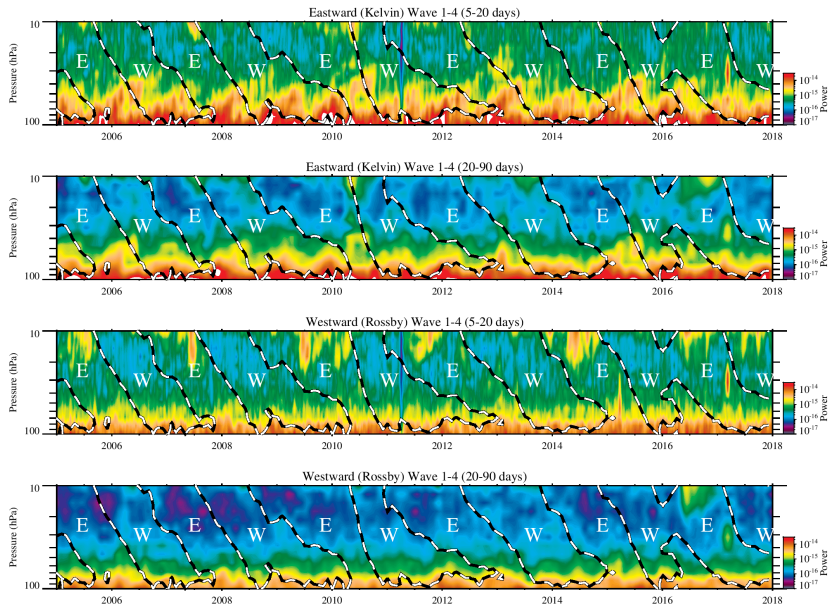
# MLS T : Power Spectrum : QBO over the last decade

Wavenumbers 1-4 : periods 5-20 and 20-90 days : (Singapore winds)



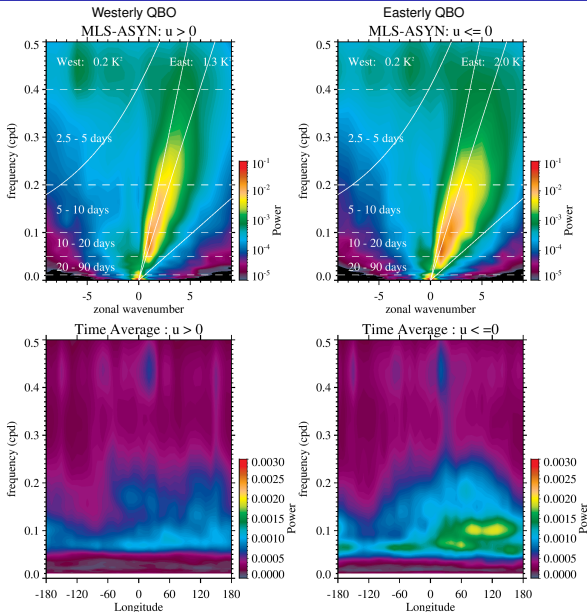
# RAs : MLS H<sub>2</sub>O : Power Spectrum : QBO over the last decade

Wavenumbers 1-4 : periods 5-20 and 20-90 days : (Singapore winds)



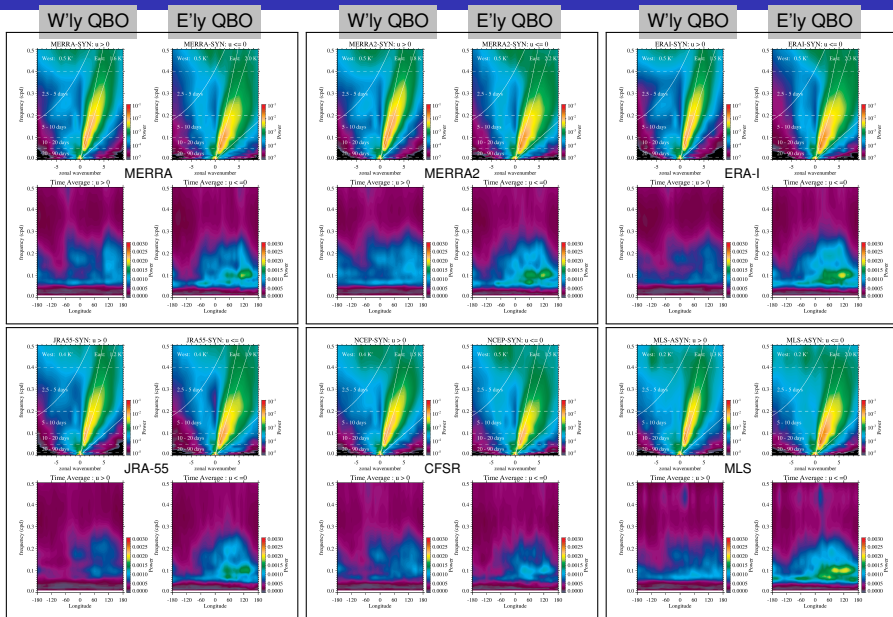
# MLS T : Power Spectra in QBO phases : 46 hPa : LS : $p \geq 90$ d

MLS :  $(k - \omega)$  upper and  $(\lambda - t)$  lower



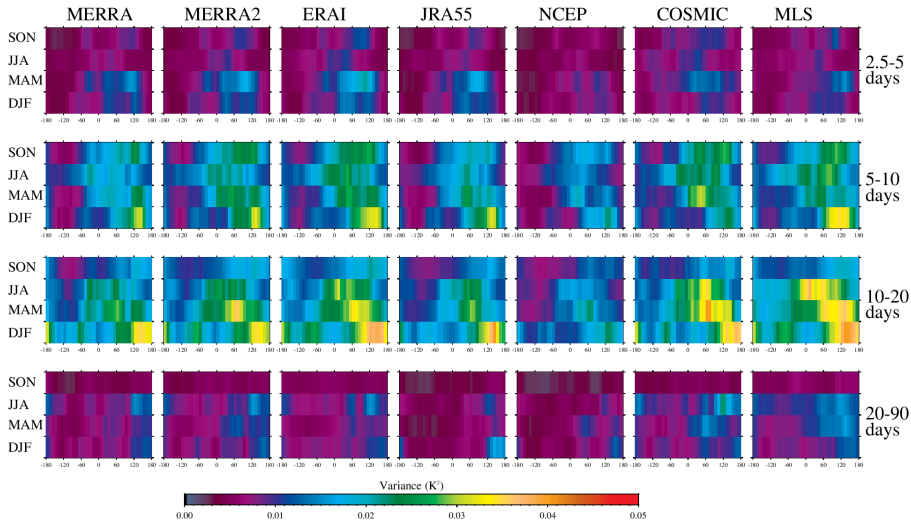
# Power Spectra in QBO phases : 46 hPa : LS

MERRA, MERRA2, ERA-Interim, JRA-55, NCEP-CFSR, MLS



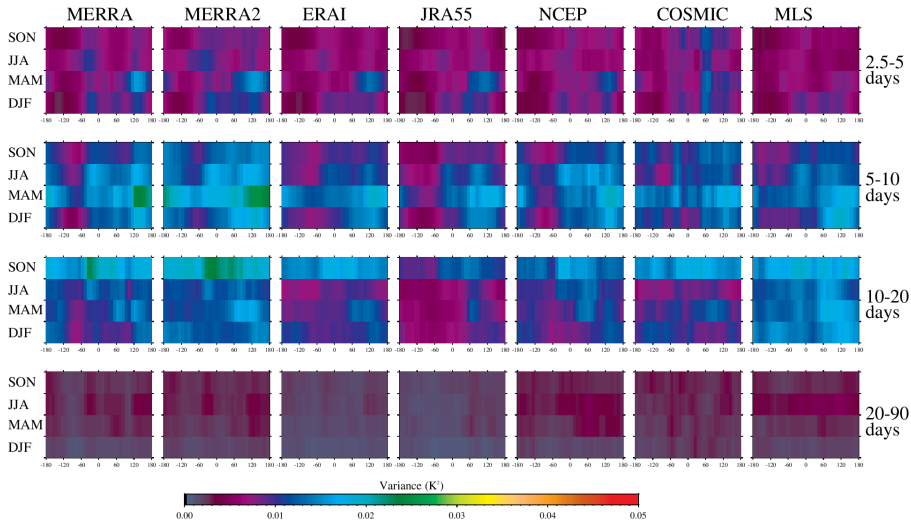
# Kelvin Wave Activity in QBO Easterly Phase : 46 hPa : LS

MERRA, MERRA2, ERA-Interim, JRA-55, NCEP-CFSR, COSMIC GPS, MLS



# Kelvin Wave Activity in QBO Westerly Phase : 46 hPa : LS

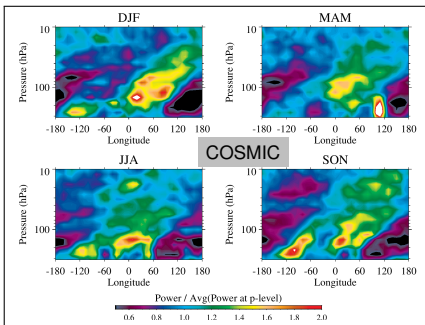
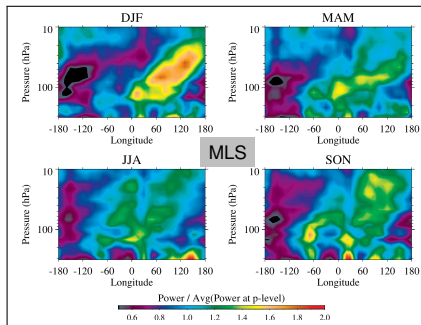
MERRA, MERRA2, ERA-Interim, JRA-55, NCEP-CFSR, COSMIC GPS, MLS



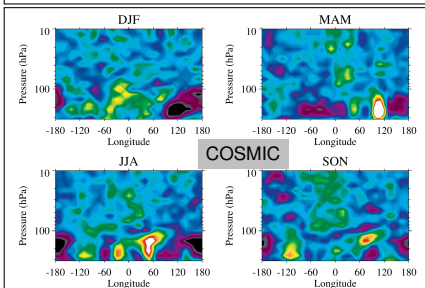
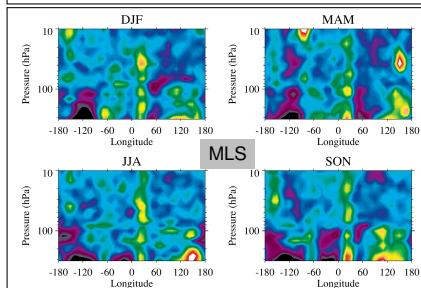
# MLS : COSMIC : Power Spectra filtered for 5-10 day periods

longitude - pressure cross-section along Equator : Eastward and Westward

E



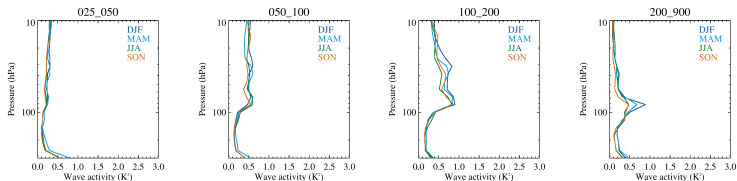
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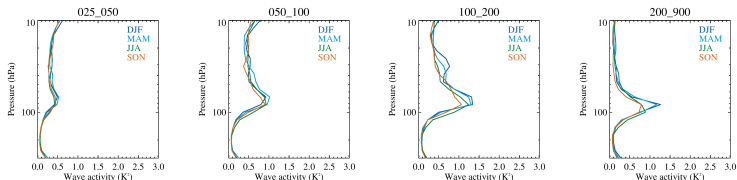
# MLS : COSMIC : ERAI : Mean Variance vs Height

Eastward : periods : 2.5-5 : 5-10 : 10-20 : 20-90 days

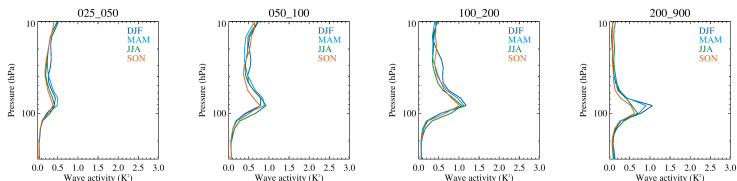
MLS



COSMIC



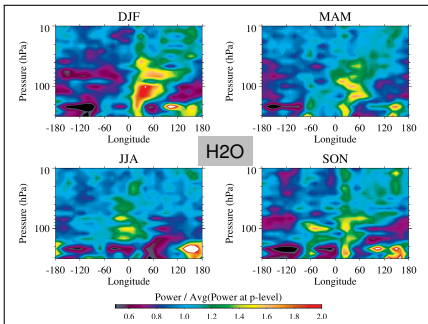
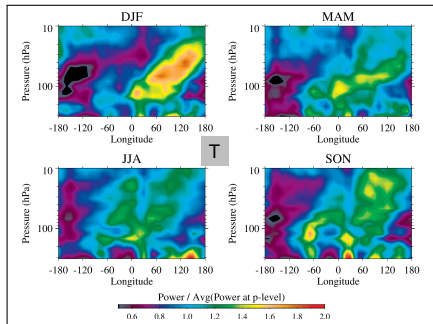
ERA-I



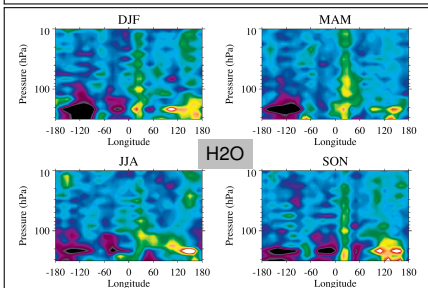
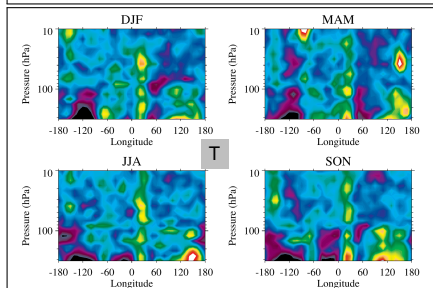
# MLS T: MLS H<sub>2</sub>O : Power Spectra filtered for 5-10 day periods

longitude - pressure cross-section along Equator : Eastward and Westward

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# MLS T : MLS H<sub>2</sub>O : Mean Variance vs Height

Eastward : periods : 2.5-5 : 5-10 : 10-20 : 20-90 days

